SAND 85-2149

HQZ.19870615.6381

SAI
T&MS
LIBRAI

A Revised Rail-Stop Exposure Model for Incident-Free Transport of Nuclear Waste

Robert M. Ostmeyer

SF2900Q(8-81)

A REVISED RAIL-STOP EXPOSURE MODEL FOR

INCIDENT-FREE TRANSPORT OF NUCLEAR WASTE

February 1986

Robert M. Ostmeyer

Division 6321

Sandia National Laboratories

Albuquerque, New Mexico 87185

ABSTRACT

This report documents a model for estimating railstop doses that
occur during incident-free transport of nuclear waste by rail. The
model, which has been incorporated into the RADTRAN III risk
assessment code, can be applied to general freight and dedicated
train shipments of waste.

This Page Left Intentionally Blank

CONTENTS

This Page Left Intentionally Blank

I. INTRODUCTION

This report documents a revised railstop exposure model for assessing the radiological risk of transporting high level radioactive waste by rail. The model, which has been incorporated into the RADTRAN III risk assessment code (Ma-86), is based on a detailed analysis of rail operations that are important for transportation risk. This analysis is documented in a report entitled "Railroad Transportation of Spent Nuclear Fuel" by D. G. Wooden (Wo-86).

The railstop exposure model can treat both general freight, where waste casks are handled like other hazardous cargo, and "dedicated" train modes of rail transport. A dedicated train, in the sense used by DOE in the NWPA program, refers to a train of 10 to 20 cars which remains intact during transport and which is not subject to frequent stops and classification. The model classifies railstop exposures into two types: close proximity employee exposures and other-rail/nonrail population exposures. For dedicated trains, close proximity exposures are to employees that inspect the trains at railstops. In the case of general freight shipments, these exposures result from train inspections and also from car classifications. Other-rail/nonrail exposures are to railyard employees not handling the shipment and to the general population that surrounds the railyard. Unlike close proximity crew exposures which are a function of the number of train "handlings," other-rail/nonrail exposures are a function of railstop time.

The report contains three sections: 1) a description of the close proximity crew exposure model, 2) a description of the general population exposure model, and 3) a summary section. A discussion of the impact of the revised railstop exposure model on incident-free waste transportation risk is given in the last section.

II. CLOSE PROXIMITY CREW EXPOSURE

Close proximity exposures are to employees that handle the rail casks during railstops. In the case of general freight shipments, the magnitude of these exposures is a function of the number of train classifications. These

exposures result from marshaling of cars, arrival and departure inspections of trains, and repair of damaged railcars. Close proximity exposures for dedicated trains are a function of the number of times that the train is inspected. For dedicated trains, these exposures are limited principally to train inspections which would occur at intervals of not more than 1000 miles.

The close proximity dose for a high-level radioactive waste cask is given by

$$CD(d) = NH(d) * HD \qquad (1)$$

where NH(d) is the number of train handlings which is a function of the transport distance d and HD is the total close proximity crew dose per shipment handling. A shipment handling refers to train classification in the case of general freight shipments and to train inspection in the case of dedicated trains.

2.1 Number of Train Handlings per Trip

Wooden (Wo-86) performed a survey to determine the number of times that a general freight shipment would be classified and inspected per full length trip. Based on analyses of the survey data, he developed the following approximation for the number of classifications likely to take place.

$$NH(d) = 2 + 0.055 * (d^{0.55}) \qquad (2)$$

where d is the shipment distance (km). The minimum of 2 classifications per shipment corresponds to the classifications that would occur at the departure and destination rail terminals.

The model given by equation 2 was incorporated into the RADTRAN III risk assessment code in the form of the following approximate relationship.

$$NH(d) = 2 + 0.0018 * d \qquad (3)$$

Because RADTRAN III is often used to calculate "unit risk factors" (i.e., risk per unit distance of travel (e.g., see Wi-83 and Ne-84), a linear model form was desired for incorporation into the code.

Wooden did not develop a similar relationship for the number of times that a dedicated train would be inspected per full length shipment. However, he did note that trains are required by regulation to be inspected at intervals of not more than 1000 miles. In addition, trains will be inspected at interline junctions to establish responsibility for defective cars. Thus, it seems likely that trains will be inspected at least once every 1600 km. The actual frequency would be higher, depending on the number of different lines that the train traversed during the shipment. The relationship for the number of train classifications given in equation 3 is used as a conservative estimate of the number of times that a dedicated train would be inspected. Use of this relationship assumes that the train is inspected at the departure and destination points to establish responsibility for car defects and at a frequency of once in every 560 km in between.

2.2 Close Proximity Crew Dose per Train Handling

The radiation dose per handling depends on 1) the number of operations per handling (i.e., times that a railyard employee is close to the railcask), 2) the distance from the employee to the railcask for each operation, 3) the time of exposure for each operation, and 4) the transport index for the railcask. Thus, the handling dose can be defined as

$$HD = TI * K_o' \sum_i T_i / r_i \tag{4}$$

where TI is the effective transport index (mrem/hr) for the shipment, K_o' serves to extrapolate the TI value (i.e., dose-rate at 1 meter from the cask surface) to the center of the cask (m) (see Ma-86), T_i is the exposure time for operation i (hr), and r_i is the exposure radius for operation i (m). The above relationship, which represents a line source, is adapted from Ta-82. This relationship can be rewritten as

$$HD = TI * K_o' * EF \qquad (5)$$

where $EF = \sum T_i/r_i$.

The factor used for EF is taken from Wo-86. As part of his analyses, Wooden developed a realistic but conservative estimate of EF = 0.16 hr/m for general freight shipments. This estimate includes operations such as arrival and departure inspection of trains, marshaling operations, and car repair. The dominant contributor to EF is the marshaling process.

In the case of dedicated trains, the estimate of EF would not incorporate doses resulting from classifications. It is assumed that dedicated trains are assembled at the originating facility. In addition, only one train inspection per train handling will occur. Based on analyses in Wo-86 for car inspection exposures, EF is assigned a value 0.01 hr/m per car inspection for dedicated trains. This estimate includes the exposure for a walk-by inspection of the train as well as the exposure for walk-by inspections of trains on adjacent tracks.

III. GENERAL POPULATION EXPOSURE

General population exposures would be to railyard employees not involved in handling the shipments and to populations in the immediate area outside the railyards. These exposures are proportional to the stoptime per full length trip. The general population dose per trip is given by

$$GPD = ST(d) * PDR \qquad (6)$$

where ST(d) is the stoptime (hr) for shipment distance d (km) and PDR is the general population dose per hour of stoptime (mrem/hr).

3.1 Stoptime per Shipment

Train stoptime at terminals will result because of train classifications, change of power, refueling, inspections and change of train crews. In the case of general freight shipments, the majority of total stoptime will occur as a result of train classifications. Stoptime for dedicated trains would result from change of crews, refueling, change of power units and inspections.

Wooden developed an approximate relationship for predicting stoptime per general freight shipment of high level radioactive waste (Wo-86). The stoptime per trip is given by

$$ST(d) = 60 + 0.02 * d + 0.86 * (d^{0.46}) \tag{7}$$

where ST(d) is the stoptime (hr) for a shipment of distance d (km).

The empirical model given by equation 7 was incorporated into the RADTRAN III risk assessment code in the form of the following approximate relationship.

$$ST(d) = 60 + 0.033 * d \tag{8}$$

This approximation to Wooden's model was incorporated because of the desire for a linear risk model (see Secton 2.2).

Wooden's report does not contain a stoptime relationship for dedicated train shipment of high level radioactive waste. However, given that dedicated trains would not undergo enroute classifications, the stoptime for dedicated trains will be substantially less than that for general freight shipments. In a personal communication, Wooden (Wo-85) noted that stoptime for dedicated trains is a function of the need for any one or more of 1) crew change, 2) locomotive change, 3) refueling, or 4) train inspection. He suggested that

the following relationship could be used as a conservative estimate of dedicated train stop time.

$$ST(d) = 2 + 0.004 * d \qquad\qquad (9)$$

where ST(d) is stoptime (hr) per full length trip of distance d (km). The relationship assumes that a crew change will occur at intervals of 250 km. A stop of one hour is assumed for each crew change. The two hours of stoptime which are not related to distance cover the change from the originating crew to the first road crew and the change from the final road crew to the delivering crew at the destination.

3.2 Population Dose per Unit Stoptime

The general population dose per unit stoptime includes doses to railyard employees not in close proximity to the railcasks and doses to the general population in areas adjacent to railyards. The magnitude of this parameter depends on the effective transport index (TI) for the shipment, the effective density of the surrounding population, and the extent of structure shielding. This dose does not include the close proximity crew exposures discussed above.

A simple approach to estimating other-rail/nonrail dose involves treating the rail cask as a point source and assuming that the surrounding population is uniformly distributed. The population dose rate is thus given by

$$PDR = PD * SF \int_{r_a}^{r_b} DR(r) * 2\pi r * dr \qquad\qquad (10)$$

where PD is the population density (people/km^2), SF is a shielding factor, and DR(r) is the dose rate (mrem/hr) at radius r (m) from the rail cask. The outer radius for integration, r_b, is assigned a value of 400 meters. With air attenuation and buildup included, the dose rate at 400 meters is nearly four orders of magnitude less than that at about 10 meters from the cask. The inner radius for integration, r_a, is assumed to be 10 meters. Doses inside of this radius are to individuals handling the waste shipments (i.e.,

close proximity exposures). These doses are included in the estimates of close proximity crew exposures.

RADTRAN III uses a simplified but conservative approach to evaluating DR(r) (Ta-82). That is,

$$DR(r) = TI * K_o / r**2 \tag{11}$$

where TI is the effective transport index (mrem/hr) for the shipment, K_o is the point source package shape factor used to relate the TI to a point source (m**2), and r is the distance between the dose receptor and the point source (m). Substitution of equation 11 into equation 10 leads to the following solution for population dose.

$$PDR = PD * TI * SF * K_o * 2\pi * \ln(r_b/r_a) \tag{12}$$

This relationship ignores the small effect of radiation attenuation by air.. With the two radii previously discussed, equation 12 becomes

$$PDR = PD * TI * SF * K_o * 23 \tag{13}$$

where PD is people/m^2.

3.2.1 Population Density

The effective population density for equation 13 incorporates a component for railyard employees and a component for populations that are adjacent to the railyard. The overall importance of each of these two components depends on 1) the average employee density for the railyard, 2) the size of the railyard, and 3) the characteristics of the area surrounding the railyard (e.g., rural, urban, suburban, or commercial).

In his review, Wooden noted that employment at a small rail terminal might average 80 persons through all shifts while a very large terminal may have an average of 500 employees. In addition, he noted that classification terminals may range in dimensions from 1.5 by 0.5 km to 12 by 1.5 km. Based

-11-

on these figures, railyard employee densities of 30 to 110 people/km^2 might represent average employee density. These average densities may be well below peak employee densities. Many railyard facilities (e.g., offices) are operated for only five 8-hr shifts a week. Peak employee densities (i.e., densities during main weekday shifts) could be from a factor of 3 to 4 larger than the average employee densities.

Areas near railyards can vary in characteristics from urban to rural. When rail terminals are located in urban environs, areas nearest to the railyards are generally utilized for commercial and industrial development. Because of the variability population characteristics, it is difficult to define an average population density for areas surrounding a "typical" railyard. A reasonable and conservative approach is to assume that the average nonrail population density is equal to that for suburban areas. A density of 719 people/km^2 is given in US-77 for suburban areas.

The effective or combined population density is a weighted sum of the rail and nonrail population densities. The weighting for these densities depends on the dose versus distance relationship, on the position of the railcasks in the railyard, and on the dimensions of the railyard. Because the latter two parameters are highly variable, it is difficult to define a "generic" population density. A conservative approach is to assume the larger of the two population densities. Thus, a density of 719 people/km^2 is assumed for RADTRAN III.

3.2.2 Radiation Shielding

Radiation exposures to the rail/nonrail populations can be reduced by two factors; radiation shielding and area occupancy. For railyard employees, shielding is afforded by buildings (i.e., shops, administrative buildings, etc.) and by trains, railcars, and other equipment in the railyard. Populations in areas adjacent to railyards will be shielded by nonrail structures in addition to structures and equipment in the railyard. Employee occupancy rates for railyards (i.e., average density divided by weekday main shift density) can be as small as 0.3 to 0.4 (Wo-85). Occupancy rates for

populations near railyards are highly variable and can range from nearly 1.0 for residential areas to about 0.25 in commercial areas.

Radiation shielding for general railyard exposures will result from railcars in the yard and from being inside of structures (e.g., offices and shops). The actual shielding factor can be thought of as the product of a railcar shielding factor and a structure shielding factor.

Assuming that railcars are randomly distributed in the railyard, the average shielding factor for railcars can be determined by

$$SF_{RC} = (\int_{r_a}^{r_b} \exp{(-\mu r)} * B(\mu r) * dr/r^2)/(\int_{r_a}^{r_b} dr/r^2) \qquad (14)$$

where μ is the "effective" linear attenuation coefficient for the shielding medium and r is the distance from the point source to the receptor point. This equation is determined by dividing the area integrated dose rate with attenuation and buildup by the area integrated dose rate without attenuation and buildup. For this equation, only attenuation and buildup due to railcars is treated. A simple form for the buildup factor is

$$B(\mu r) = 1 + \alpha\mu r \qquad (15)$$

where α is a fitting parameter that depends on gamma energy and on the type of attenuating material. For iron, α is 1.24 for 1.0 MeV gammas and is 1.43 for 0.5 MeV gammas (Mo-73). Iron is a major component in steel used to construct railcars.

The linear attenuation coefficient, μ, for the above equation is determined by multiplying the mass attenuation coefficient for the attenuating material by the "effective" mass density of the material. For iron, the mass attenuation coefficient is about 0.06 cm^2/g for 1.0 MeV gammas and is about 0.084 for 0.5 MeV gammas (US-70). The "effective" density for the attenuating medium is determined by dividing the total mass of railcars per km^2 of railyard by the attenuating volume. In this case, the volume is the average

height of the railcars multiplied by Km^2. From AS-74, the typical weight of an empty railcar is 27,000 kg with an average height of about 4.5 m. The maximum load of these cars is often about three times the empty weight (AS-74). Thus, assuming that 50 percent of the cars are empty and that 50 percent of the cars are loaded to double their empty weight, the average car weight is about 41,000 kg. Based on statistics in Wo-86, the average density of railcars in rail terminals is about 500 cars per km^2. Thus, the effective density is about 0.0045 g/cm^3. The attenuation coefficients are then 0.027 m^{-1} for 1.0 MeV gammas and 0.038 m^{-1} for 0.5 MeV gammas. Evaluation of equation 14 with r_a = 10 and r_b = 400 m results in an estimate of SF = 0.52 for 1.0 MeV gammas to 0.45 for 0.5 MeV gammas.

Most railyard employees work inside of some type of structure. The exception to this case are yard crews that spend a substantial fraction of their time working outdoors. Depending on the type of structures, the number of partitions in the structures, the position of employees in structures, and the amount of furniture and/or equipment in the structures, structure shielding can reduce doses to employees in buildings by a factor of two to more than a factor of ten (Bu-75). Thus shielding factors of 0.1 to 0.5 are possible.

Structure shielding for populations near railyards can be highly effective. Unless the railyard is in a rural area, most areas near rail terminals are commercially or industrially developed. These areas may include warehouses which contain freight and other goods. In addition, structures in these areas are likely to be heavy with significant use of concrete and masonry construction. Shielding factors for these areas may be comparable to those for areas classified as urban. A factor of 0.018 is given in Ta-82 for urban type areas. In US-75, structure shielding factors for ground deposits of radionuclides range from 0.08 to 0.001 for the first and upper floors of multistory structures. Based on these data, it seems likely that an average shielding factor of at least 0.1 is possible for populations adjacent to railyards.

The composite shielding factor (which includes employee occupancy rates) for the other-rail/nonrail population is not easily defined. A conservative estimate of the average shielding factor for railyards employees is about 0.25. This factor incorporates the factor of 0.5 for railcar shielding and a factor of 0.5 for structure shielding. Since the average shielding factor for nonrail populations is probably less than 0.1, and since rail employee densities are less than the suburban population density assumed for this model, a shielding factor of 0.1 is selected for use in the railstop exposure model.

IV. SUMMARY AND DISCUSSION

4.1 Railstop Model Summary

The railstop model described in this paper can treat both general freight shipments and dedicated trains in incident-free radiological risk calculations. Railstop exposures are broken down into two classes: close proximity exposures to employees handling the shipment and other-rail/nonrail population exposures. The close proximity exposures are proportional to the number of times that a waste shipment is handled and are not necessarily proportional to total stoptime. General population exposures are, on the other hand, proportional to total railyard stoptime. The equations and data incorporated into RADTRAN III to estimate railstop doses for each railcask are summarized in Table 1 for general freight and dedicated train shipments of high level radioactive waste and spent fuel.

4.2 Relative Importance of Railstop Exposures

RADTRAN III calculations were performed to estimate population exposures for incident-free transport of waste by rail. The results of these calculations are shown in Table 2 for both general freight and dedicated train shipment of nuclear waste. Assumptions used for the calculations include 1) an effective transport index of 0.1 mrem/hr and 2) a shipment distance of 2600 km. The on-link train speed was assumed to be the same for the dedicated train and general freight shipments.

-15-

Comparison of the railstop doses for the dedicated train and general freight modes shows greater than an order of magnitude difference in dose. (Total stoptime dose is the sum of the close proximity crew and general population doses.) However, because of the importance of exposures that occur during train movement, total incident-free transport dose differs by less than a factor of four for the two shipment modes. Doses during train movement account for about 23 percent of the calculated dose for the general freight mode and for about 80 percent of the dose calculated for the dedicated train mode.

Table 1.   Railstop Dosimetry Relationships for General Freight and Dedicated Train Shipment Modes

Dosimetry Relationships:	Parameters	
	General Freight	Dedicated Train
Close Proximity Crew Dose:		
$CD(d) = (2 + 0.0018d) * TI * K_o' * EF$	$EF = 0.16$ hr/m	$EF = 0.01$ hr/m
General Population Dose:		
$GPD(d) = (a + bd) * PD * TI * SF * K_o * 23$	$a = 60$ hr	$a = 2$ hr
	$b = 0.033$ hr/m	$b = 0.004$ hr/m
	$SF = 0.1$	$SF = 0.1$
	$PD = 719$ people/ km^2	$PD = 719$ people/ km^2
	or $7.2(10^{-4})/m^2$	or $7.2(10^{-4})/m^2$

Table 2. Comparison of Population Dose for Incident-Free Transport of
Waste by General Freight and Dedicated Train Modes

Dose Category	Population Dose (rem/trip)	
	General Freight	Dedicated Train
While Moving	$3.7(10^{-4})$	$3.7(10^{-4})$
Close-Proximity Crew	$7.1(10^{-4})$	$4.5(10^{-5})$
General Population	$5.4(10^{-4})$	$4.2(10^{-5})$
Total	$1.6(10^{-3})$	$4.6(10^{-4})$

REFERENCES

AS-74   Associated American Railroads, Car and Locomotive Cyclopedia of
         American Practices, Simmons-Boardman Publishing Corporation, New
         York, NY, 1974.

Bu-75   Z. G. Burson and A. E. Profio, Structure Shielding from Cloud and
         Fallout Gamma Ray Sources for Assessing the Consequences of Reactor
         Accidents, EGG-1183-1670, EG&G Inc., Las Vegas, NV, 1975.

Ma-86   M. M. Madsen et al., RADTRAN III, SAND84-0036, Sandia National
         Laboratories, Albuquerque, NM, 1986.

Mo-73   K. Z. Morgan and J. E. Turner, Principles of Radiation Protection,
         R. E. Krieger Publishing Company, Huntington, NY, 1973.

Ne-84   K. S. Neuhauser, J. W. Cashwell, P. C. Reardon, and G. W. McNair, A
         Preliminary Cost and Risk Analysis for Transporting Spent-Fuel and
         High-Level Wastes to Candidate Repository Sites, SAND84-1795,
         Sandia National Laboratories, Albuquerque, NM, 1984.

Ta-82   J. M. Taylor and S. L. Daniel, RADTRAN II: Revised Computer Code
         to Analyze Transportation of Radioactive Material, SAND80-1943,
         Sandia National Laboratories, Albuquerque, NM, 1982.

US-75   United States Nuclear Regulatory Commission, Reactor Safety Study,
         WASH-1400, NUREG-75/014, Washington, D.C., 1975.

US-77   United States Nuclear Regulatory Commission, Final Environmental
         Statement on the Transport of Radioactive Material by Air and Other
         Modes, NUREG-0170, Washington, D.C., 1977.

Wo-86   D. G. Wooden, Railroad Transportation of Spent Nuclear Fuel,
         TTC-0574, SAND86-7083, Sandia National Laboratories, Albuquerque,
         NM, March, 1986

Wo-85   D. G. Wooden, Personal Communication, DGW Services Inc., St.
         Albans, VT, 1985. (See Appendix A)

APPENDIX A

This appendix contains excerpts from Wooden's letter (Wo-85) that are pertinent to the new railstop model.

"Dedicated train service would differ from ordinary carload service mainly in that the enroute classification of cars between trains would be eliminated. Other than for periodic stops to change crews, locomotives, add fuel and/or perform inspections, the spent fuel shipments would move continuously from origin to destination, barring mechanical breakdown."

"Stop time not in trains under dedicated train service is merely the time of train changeover points. Train changeover points are those where one or more of the following would take place: 1) crews change, 2) locomotives change, 3) locomotives are refueled, or 4) the train is inspected. There will be very few instances where the train is stopped solely to inspect it. We believe it will be conservative to assume that a train changeover will take place two times on each dedicated train trip plus one time for each 250 km. of haul. A reasonable stop time for changeover would be one hour. The two times which are unrelated to distance cover the changeover from the originating crew to the first road train and the second change from the final road crew to the delivering crew at destination."

"Train changeovers will usually take place at rail classification terminals; however, the location within the terminal will not be in the yard tracks; but on the main running tracks. Such tracks are typically located to one side of the yard tracks. The short dedicated train will stop closest to where the crews are dispatched, or at the main track refueling facility. The shipment will not be surrounded by a large population of standing cars to provide shielding to the employees working in the general area or to the adjacent population, at least on the side of the terminal on which the main tracks are located. Thus, exposures to these groups per hour of stop time could be higher than for ordinary cars undergoing classification in the yard."

DISTRIBUTION:

U. S. Department of Energy
Office of Scientific & Technical Information (226)
Oak Ridge, TN 37830
Attn: DOE/OSTI-4500-R74 UC-71

U. S. Department of Energy
Routing DP 123
Washington, DC 20545
Attn: T. Hindman
       R. Heusser
       F. Falci

U. S. Department of Energy
Albuquerque Operations Office
2201 San Pedro, NE, Bldg. 3
Albuquerque, NM 87110
Attn: J. McGough
       K. Golliher
       E. C. Hardin

Joint Integration Office
2201 San Pedro, NE; Bldg. 3
Albuquerque, NM 87110
Attn: J. Roll, Westinghouse
       K. McKinley, Rockwell
       R. M. Jefferson

U.S. Department of Energy
Routing RW-33
1000 Independence SW
Washington, DC 20585
Attn: L. Barrett (1)
       R. Philpott (1)
       E. Wilmot (10)
       S. Denny (1)

Office of Security Evaluations
Attn: Dr. Julio L. Torres, Acting Director
Defense Programs - DP-4, GTN
Washington, DC 20545

Environmental Evaluation Group
Attn: D. L. Shomaker, Librarian
P.O. Box 968
Santa Fe, NM 87503